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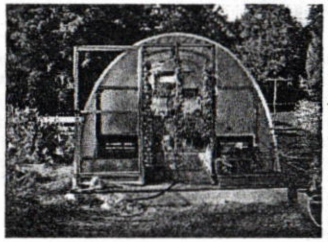
Article

Building an Inexpensive Greenhouse

By Chris Pratt

It is late fall, the leaves are gone, and the nights are cold. The garden has been bedded down for the winter with a green manure crop to prepare it for spring. You come in with an armload of wood, take off your winter coat and set down to a fresh green salad with loose leaf lettuce, spinach, shallots, basil and tomatos. All picked fresh moments ago. Welcome to the Greenhouse!



One cannot say enough about how nice it is to have a greenhouse. Prior to building it, we never had a season where jalepenos and cayenne peppers (our passion at the dinner table) would come to full maturity. Kim learned how to make many jars of green tomato salsa (by necessity). The growing season in Western Washington State is barely adequate to grow a successful garden.Our greenhouse is a necessity rather than a nicety (we just didn't know it prior to building it).

The Design

We saw an article in Countryside Magazine that talked of using welded wire stock panels (wires welded to form a fence partition, see Figure 1) with both edges held down to form a quansot hut style greenhouse. This design called for pounding re-bar into the ground and wiring the edges of the stock panels to the re-bar. The top of one panel is then wired to the bottom of the next and so on. At the ends, you use some sort of framing to stiffen. Everything is then covered with translucent fiberglass panels.

This is how we planned it and how we based our purchases, but as so many of our projects go, quite different from what we built. The first thing that had to go was re-bar. The place we picked for the greenhouse, had a substance that while appearing to be dirt, is really closer to concrete. The re-bar lost the contest and would bend rather than be pounded in! The second problem was headroom. The stock panels would not be high enough if they were flush with the ground. The last was the fibreglass panels. The fellow at the building supply talked us out of this as he felt they would be cracking constantly at the place they were wired on. On to plan B.

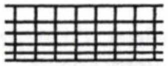


Fig. 1 Welded Wire Stock Panel

How we built it

What we built was actually a frame of 4x4s to support the wire structure. These were placed in a "basement" on pier blocks. The stock panels were attached to the frame, the ends framed, and greenhouse plastic placed over the entire structure.

The process began by scraping out an 8 1/2 x 22 foot hole approximately 12 inches deep using out loader. Then we leveled it by hand. We placed the pier blocks where they would appear to provide the greatest support and created a 8 x 20 square of 4x4s at just above ground level (each 4x4 was attached to the next by steel plates and screws). This 4x4 frame was nailed to the pier block's steel bracket.

The frame being completed, we got out the bolt cutters and cut off the little ends sticking out on the stock panels (see Fig. 1). We then laid the stock panels out so that one end was flush with one side of the 4x4 frame. This end was nailed down using giant fencing staples (we did not drive these home at this point so that we could make any adjustments that might be necessary). The BIG MOMENT. We made the first bowed section by one of us pushing the free end towards the center (see Fig. 2).

Fig. 2 Stock Panel with sides pushed in forcing a bow

The free side was now nailed to the other side of the frame and viola... we had something that resembled a structure. We repeated this procedure for 5 stock panels using baling wire to wire each one to the next until we had something similar to Fig 3.

Fig. 3 Several Sections on 4x4 frame held up by pier blocks. Sections are held together by baling wire.

Using all those old scraps of 2x4s that are left over from projects, we framed the ends. The north end was given a special treat, 2 sections of 1/2 inch plywood (something we avoid using since it cant be milled) with holes cut out

Make Your Own Pop Bottle Drip Irrigation System

by Gayla Sanders

Drip Irrigation System in between basil plants

The last time I forgot to water my outdoor potted plants and discovered them completely wilted and hanging on the cusp of near death, I decided it was time to take action. Some of the plants on my deck receive a full, searing sun all day long during the hottest mid summer days. While these plants thrive under such conditions if properly taken care of, they will die quickly if they don't receive enough water. Although it has been unusually rainy this year in these parts, full sun deck plants will still get extremely hot and dry very quickly.

One of the best ways to provide a steady water supply to your plants without your constant attention is the gradual watering system or drip irrigation. Through this method a device is employed that slowly delivers water into the soil directly around the roots. Commercial watering spikes can be purchased from you local garden centre however, using recycled materials you can make your own drip irrigation system for free.

Drill 4-8 small holes into the plastic cap

The materials you will need are as follows:

1. 2 litre plastic soda bottle or water bottle that still has the lid
2. drill and small drill bit
3. sharp knife
4. cutting surface

Drill 4-8 small holes into the cap of the plastic bottle. If you want it to drip slower use less holes, faster use more holes. Don't make holes that are too small, they will become clogged up by debris. Remove the bottom of the bottle by cutting vertically across with a sharp knife. I find a serrated knife works well. Removing the bottom of the bottle creates a funnel for you to easily pour water into. The wide mouthed opening will also catch some water when it rains.

Dig a hole in between a grouping of plants

Dig a hole next to a plant or in between a grouping of plants that is deep enough to bury at least one third to one half of the bottle. If you position the bottle in amongst a grouping of plants it will be hidden from view. Place the bottle in the hole with the cap side down and secure it into the hole by pressing dirt around it. This will ensure that your bottle stays in place. Pour water into the bottle until it is full. You can add fertilizer to the bottle every few weeks so that your plants are fertilized right at the roots.

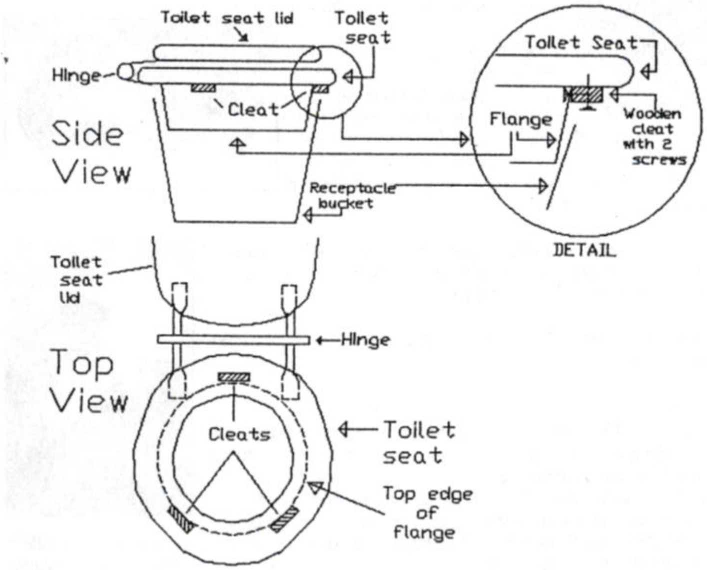
You will need to fill your bottle when it is empty, once a day or less depending on how much direct, hot sun your plants receive. Make several bottles to place in all your large containers or next to plants in your garden such as tomatoes that require a lot of water.

Fill the bottle to the top with water or fertilizer

Related Articles
We've got more water conservation tips for you
Another diy water saving project: rain barrels

This simple composting toilet system is inexpensive both in construction and to operate and, when properly maintained, aesthetic and hygienic. By closing the human nutrient cycle, it is a perfect compliment to organic gardening. In many ways it out-performs complicated systems costing hundreds of times as much! Although it may lack appeal in first world countries with their expensive, "out of sight, out of mind" sewage systems, it may be highly appropriate in areas that lack such complex infrastructure.

We recently tested a simple ventilation system to capture odors during use and vent them outdoors. This common-sense, basic capability is something lacking in almost all toilets, even in the wealthy industrialized countries. The American approach is to ventilate the toilet *room* by a fan installed in the ceiling. This makes some sense, as this approach will also ventilate a shower or bath. However, a much more effective approach, which *prevents* any odors from even escaping from the toilet, is to ventilate the toilet itself. You can achieve this by attaching a flexible air suction hose to the toilet flange powered by an electric fan which sucks air from the room and vents it either into the normal ventilation stack or through the wall to the outside. Our simple contraption consists of a second hand vacuum cleaner, a 2" check valve to prevent odors or outside air from flowing backwards into the room, a dimmer switch to lower the power (and therefore noise) of the vacuum, and a few pieces of 2" or 3" pipe to route the air flow. Total cost is less than $35 (vacuum: free, check valve: $17, other plumbing parts for routing air: about $5, dimmer switch and other electric parts: $10). The fan device is actuated for only a few seconds during use, until new deposits are covered when no further odors are present. This method works flawlessly and prevents *all* odors, *all the time*. For those who don't want to re-invent the wheel, I have come across a commercial version of a toilet ventilation fan, although I cannot vouch for whether it works well. Basically, it appears to be a thin device that fits between the usual toilet seat and the porcelain fixture. It ventilates air in its proximity with an electric fan. The following simple diagram shows the basic plan for this toilet(not including the ventilation device). The air suction device (connection by some type of flexible hose) attaches to anywhere on the flange.



for louver vents and a fan. The south end got a screen door cut down to about 5 1/2 feet and 2 louver vents. The entire structure was covered with a professional greenhouse plastic.

To seal in the "basement" we bought sections of a type of board that contains concrete. Using a worm drive skil saw we cut these boards in strips to go from the ground (down in the hole) up to the edge of the 4x4s. These were then sealed at the top with a sealer, and backfilled at the bottom with dirt. We then filled the entire interior with about 6 inches cedar chips.

Water

Though running water would be nice, we decided to use a 50 gallon food grade olive barrel to hold the water we use. This has to be filled once in a while but it has the advantage of storing heat (it is a dark gray color). We purchased a plastic valve, a section of pipe with threads on both ends and some plastic nuts to go on it. We cut a hole the size of the pipe, put a nut and o-ring on both the inside and the outside of the hole. The we screwed the valve on the end that protrudes.

Since the barrel spigot is at the bottom, we have an old cable spool that we set it on. It was free and is strong enough to hold the barrel when it is full. The bottom section of the spool doubles as storage for all the little tools we keep for greenhouse gardening.

Heat

We limped by for sometime with a small thermostatically controlled electric heater. Even during the summer there were occasions when the cool of the night would allow the temperature to drop below acceptable limits. We are in the process of installing a propane heater (non-vented) and a large tank. This should be the most effective method of keeping the greenhouse warm. We also purchased a cover that can be placed over the entire structure in the evenings and even left on during really cold spells. It reduces the light by a small amount but provides excellent insulation. While this may sound like a lot of bother, it is well worth the effort when you see the results.

Light

We are using Halide Track lights to extend the daylight. To achieve coverage of the entire growing area required two lights and tracks. These make a full pass every 40 minutes. The downside of this is the cost. Each bulb is 75 dollars. With the short days of winter, we would not be able to keep the peppers blooming without them.

Cooling

The first morning we had the greenhouse complete and covered, the temperature soared to 120 inside. We realized that without good cooling, we had simply created a solar oven. We installed a vent in roof, 4 solar-hydraulic vents in the ends, and a fan in the north end.

The vents are really inexpensive for what they do. They have a hydraulic fluid that opens and closes them based on temperature. No motors, pumps, or electricity, just very sensitive fluid. These ran about 14 dollars apiece. We made covers for the vents that can be put on at night so that no heat can escape through the louvers.

The fan is built for greenhouse use. This is important because the moisture can ruin an electric motor. There are louvers that open when the fan is on. It is hooked to a thermostat that turns it on when the temperature reaches 70 degrees. We found that we must open the glass in the screen door to allow the volume of air required by the fan. The small vents are insufficient to avoid a low pressure situation.

Growing Boxes and Tables

Plants are set on tables in the greenhouse instead of the floor so that warm air can circulate below them. These tables are typically called "benches". After looking at expensive benches in several mail-order catalogs, and after looking at more benches in books checked out from the library, we built our own benches out of used lumber. We purchased white plastic latice for the top of the benches. The tops can't be solid... they need to let air and water through. We built a total of three 8 foot long benches. Two were set on one side of the greenhoues, one on the other. On the side of the greenhoues with only one bench, we built a 9 foot by 4 foot raised bed (also out of used lumber).

We also built four "growing boxes" especially for raising salad vegetables. The boxes are made of used wood and are about 24 inches by 16 inches, and about 6 inches deep. In the first box we planted lettuce, spinach and shallots. We planted the second box 3 weeks later... the third box 3 weeks after that... and the fourth box 3 weeks after that. By the time you have planted the fourth box, the first box is ready to eat and provides about 3 weeks worth of salads for us. We then replant it and move on to eating the second box which is now ready to eat. And so on, we cycle through the salad boxes in a continues eat-plant cycle.

Crops

In the past we have grown the following crops in our greenhoues:

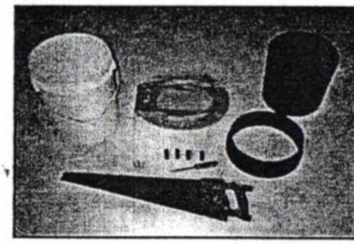
- Many Varieties of Peppers
  - Tabasco
  - Jalepeno
  - Habanero
  - Anaheim
  - New Mexico
  - Chile De Arbol
  - Cayenne
  - Bell Pepper
  - Pimiento
  - Pepperoncini
  - Serrano
  - Passilla
  - Piquin

How to make and use a simple "sawdust" toilet

My version of a "sawdust toilet" (as described in the *Humanure Handbook*) consists of a receptacle bucket, a removable toilet seat that slips into the top, and a bucket of sawdust for covering after each use. When the toilet is full the seat is switched to the empty sawdust bucket. The toilet is emptied, cleaned and sanitized and then becomes the sawdust bucket after filling with clean sawdust. The whole toilet system, including outdoor compost chamber, can be constructed for less than $10. This simple, inexpensive, and hygienic toilet -- affordable to construct and maintain by just about anyone on the planet -- is a perfect example of an appropriate and sustainable technology.

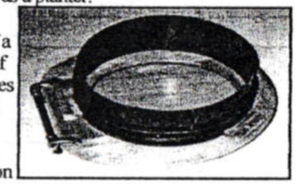
Materials: three or more plastic 5-gallon buckets, one toilet seat, 6 wood screws, and 3 small pieces of wood that function as cleats (approximately, 1 inch wide by 3 inches long by 3/4 inch deep). You will also need a compost chamber; mine is constructed from recycled wooden pallets held together by wire at the corners (see photo 5).

Tools needed: wood saw, screw driver



Steps:

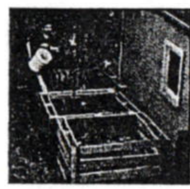
1. Using a wood saw, cut the top 4 to 6 inches off one of the buckets. This will serve as a flange to which a toilet seat is attached, allowing it to slip inside a second bucket. (See photo at left.) The bottom part of the cut bucket can be recycled, for example as a planter.



2. Attach this flange to the bottom of a toilet seat using two screws at each of three wood cleats. One screw attaches the cleat to the toilet seat; the second attaches the bucket flange to the cleat. (See photo at right and the three drawings below.) The four small brown objects in the photo, the original toilet seat spacers, are removed and discarded. The completed receptacle with flanged seat in place on a receptacle bucket is shown at the top of this page.

3. A second bucket contains sawdust, chipped wood, chopped straw, cereal hulls, or other absorbent carbon-rich organic matter. Covering with several cups or handfuls of this matter after each use effectively prevents odors. (See photo at right.)

4. When the receptacle bucket is full transfer the flanged toilet seat to the now empty sawdust bucket which then becomes the receptacle.



5. Empty the toilet contents into a composting chamber (left) and cover with a fresh layer of sawdust to prevent odors and present an aesthetic appearance. Clean the empty receptacle and sanitize and freshen in sunlight. This bucket, after filling with clean material, then becomes the sawdust bucket, and the cycle starts over. This step is the only time when odors are present, and only momentarily. Although not necessary, some individuals collect urine separately in a sealable container (such as an inexpensive but sturdy plastic bottle) because of its high value as a nitrogen source. It can be diluted by 5 parts water and put directly on plants.

  - Paprika
- Loose Leaf Lettuce (2 kinds)
- Romaine Lettuce
- Shallots
- Spinach
- Herbs (Cilantro, Basil, Oregano, Lemon Balm, Marjoram)
- Potatoes (Yes, Potatoes!)
- Carrots
- Peas
- Tomatoes
- Brussel Sprouts
- Brocolli
- Kale
- Cauliflower

Cost

While we ended up investing quite a bit on our greenhouse (this is relative, many people spend more on a new TV), we have not even approached the cost of buying a pre-fabricated shell. Our money is tied up in equipment to make the greenhouse a year-round productive garden rather than being tied up in the basic structure. The lights, heating, and cooling represent the majority of the cost. If the costs seem restrictive, remember that you will pay the same money over a year to get fresh organic produce during the off-season. For us, hot peppers, sweet peppers, and tomatos alone can nearly justify the cost. To go a step further, the greenhouse can produce income buy selling off culled plants or starts at the beginning of growing season. The size of our greenhouse provides ample produce for us. If we were to add two more stock panel sections, the extra space could be used to grow produce for local markets, and this is without any additional costs (beyond building the structure).

Many components in our greenhouse can be obtained second hand for free or nearly nothing. These are:

- Stock Panels (any farm with cattle)
- Pier Blocks & 4x4s (a good replacement would be bricks or rocks with mortar and a 2x6 ledger on top)
- Louvers for Fan (scrap yards)
- All wood
- Wood Chips
- Food Grade Water Drum

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Rob: A wonderfully detailed overview of solar hot water systems, complete with schematics and technical information, is found in the Solar Water and Pool Heating Design and Installation Manual from the Florida Solar Energy Center at (407) 783-6300. Triple A Solar in Albuquerque, NM (800-245-0311) sells used solar-thermal collectors at good rates. Check out local sources of used panels to avoid shipping costs. Six Rivers Solar (816 Broadway, Eureka, CA 95501) at (707) 443-5652 sells a high-quality, rectangular thermal storage tank that integrates the inputs and outputs of collectors, auxiliary heating sources, DHW, radiant floors, and hot tubs (Fig. 1).

Rob Harlan, Mendocino Solar Services, 42451 Road 409, Mendocino, CA 95460

Michael Hackleman, PO Box 327, Willits, CA 95490. E-mail: mhackleman@saber.net

month or $551 annually. Propane at $1.41 per gallon costs about $26 a month or $307 per year. Natural gas and fuel oil are less, as is electricity in other parts of the country. Of course, when a solar water heating system is installed and has returned the investment, the energy from it thereafter is free.

Mh: Will you give me an idea of how long it will take to pay off the cost of several of these systems based on these rates?

Rob: I have that information, too. First, let me say that these figures do not include the cost of maintenance, the rise in the cost of utility electricity, the lost interest on the investment, and no tax on the savings. In my experience, these balance each other out.

A new integral collector/storage system using the ProgressiveTube™ design will cost about $2,500 parts and labor to install. After 7.3 years, the system cost will equal the cost of electricity to heat the same water during that time. With propane, it's about 13 years. If the owner installs the system, the cost is about $1,600. The payback is 4.8 years for the avoided cost of using electricity and 8.7 years if using propane.
A new drain-back system costs $3,500 parts and labor. This is equal to 8.5 years of electricity and 15.2 years for propane for domestic hot water. A system that will heat a hot tub will cost about $4,800. When heated electrically, the payback computes to 7.5 years.

Mh: In my experience, folks who install their own solar water heating systems usually begin by putting one collector in a loop to the existing water heater. If you shower in the morning, what's the conventional method for preventing the water heater from using electricity or propane to reheat this water before the sun gets a chance at the task?

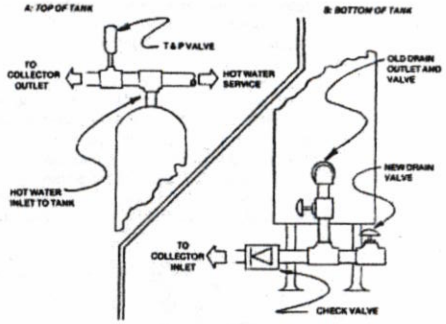


Fig. 13: Plumbing for an open system using thermosiphon

Rob: In an electric heater, it's easy. A 24-hour timer can be set to lock out the backup heating during daylight hours. The owner can manually override the timer with the flip of a switch during bad weather or unusually high demand. For a propane or natural gas heater, turn the gas valve to the pilot position.

Mh: There is a proper way to plumb the solar collector to the standard water heater, too. Today's water heaters position the cold-water inlet and hot-water outlet at the top of the tank. Cold incoming water to the tank actually drops through a tube inside the water heater which ends just above the bottom of the tank. For thermosiphon flow, this is not a good arrangement; you want the cold water return to the collector to exit directly from the bottom of the tank (Fig. 12). Fortunately, water heaters have a drain valve. There is a way to re-arrange this plumbing (Fig. 13) so that the collector will use this orifice for its thermosiphon loop while you retain the ability to drain the tank.

If someone wanted to assemble their own solar water heating system, what's a good source of information and parts, beyond the library and internet?

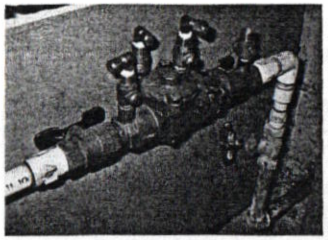
Rainwater Harvesting and Purification System

In January 1996 we installed a rainwater catchment system to capture Oregon's abundant rainfall. Portland receives between 3 and 4 feet of rainfall annually. During a gentle rain a typical Oregon downspout sheds several gallons per minute. Our twelve hundred square foot roof captures on average 3600 cubic feet (27,000 gallons) of water per year.

In 1998 we received approval from the city of Portland to use this water for all household use. This system, which cost less than $1,500, consists of the following components:

- A 1500 gallon plastic cistern, approximate cost: $500. Purchased from Northwest Irrigation, Tangent, Oregon, 541-928-0114. Contact local agriculture/farm stores for best prices.
- A 1/2 horsepower shallow-well pump to pressurize the water to between 20 and 30 psi (pressure is adjustable), approximate cost: $250. I utilized a Jaccuzzi brand pump.
- Plastic (outdoor PVC and indoor CPVC) piping to connect to the household cold water system.
- Two particulate filters in series, rated at 20 and 5 micron particle size, approximate cost: $20 each; replaceable filter cartridges cost $3-5 each.
- An ultraviolet light sterilizer capable of sterilizing water at 10 gallons per minute. This appliance was recently approved for use in Oregon. I used the PURA (1-800-292-PURA, Valencia, California) model UV20-1, cost approximately $350. Uses about 40 watts. Fluorescent ultraviolet light rated at 9600 hours, about one year of continuous use. Replacement cost of fluorescent tube: about $80.
- Screen covering the cistern to prevent entry of mosquitoes and to catch any large particles that make it past the gutter screening.
- A roof-washer which wastes the first 7.5 gallons of captured water which has "washed" the roof. Once the roof washer has filled, the rest of the water flows to the cistern. See below for details.
- A 20 gallon water butyl rubber diaphragm pressure storage tank, approximate cost: $150.
- A reduced pressure backflow prevention device. This was required by the city to prevent flow of rainwater into the public system. Cost: $120. This would not be necessary if we used rainwater exclusively. However, Oregon has very dry summers and our cistern is exhausted by July. We currently depend on city water during the summer. The city requires annual inspection of these devices, costing about $30. (See photo below.)
- A (optional) water meter to measure rainwater output, approximate cost: $45.

Maintenance consists of

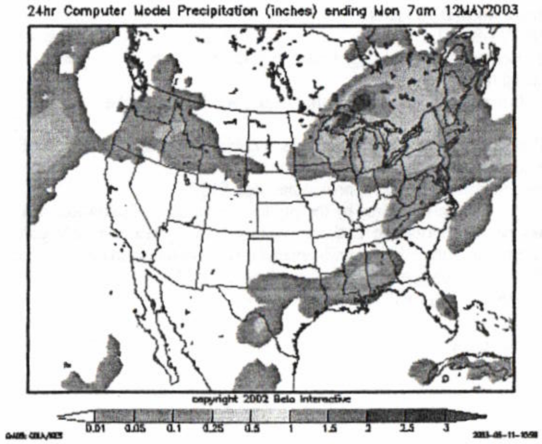


keeping gutters and cistern screen clean. Filters and ultra-violet lamp will need periodic replacement. The tank is thoroughly cleaned annually in the summer when it empties. Backflow prevention device requires annual inspection. Public health authorities recommend periodic testing of water for fecal coliform bacteria, as for any private water system. Several recent tests showed none. The inside components of our system, pictured here, take up about 6 square feet of floor space.

At the current time we continue to use the public water supply only for summertime water and occasional drinking and cooking. In fact, during the rainy season, which lasts from about September to June, our only connection to the public utility is one faucet at the kitchen sink which uses less than one gallon per day, which got us into hot water with the city water bureau.

In my research on rainwater catchment systems the best single reference I have come across for detailed design guidelines is the Texas Water Development Board's *Texas Guide to Rainwater Harvesting*.

24hr Computer Model Precipitation (inches) ending Mon 7am 12MAY2003



Roofwashers. A simple prototype is shown in the TG. It consists of a length of pipe for storage of the initial flush of water with a trickle valve (hose bib just slightly opened) and clean out valve at the bottom. Only when the this pipe fills is water then allowed to continue into the cistern. It's very simple, no moving parts. The only thing I would change is to have a narrow section or trap configuration at the top to reduce mixing of the flush water with the still arriving (clean) water. Yet another method to aid this is to add a lightweight (like styrofoam) ball that would seal the intake when the roof washer fills. This simple design is very inexpensive, easy to drain or clean manually, and works very well. The TG suggests one gallon of washer capacity for each 100 square feet of roof. So make your roof washer pipe length long enough. For our model we used 20 feet of 3" ABS. We made it in the shape of a giant U to get this length. Remember, volume equals length times area. Area equals pi times radius squared (in our case 3 inches internal diameter, or .25 foot) and one cubic foot equals 7.5 gallons. To avoid long lengths of roofwasher pipe, it makes sense to

that is drained back will have a place to go. This is my favorite choice of a system for freezing climates.
The drain-down system has the merits of high efficiency and is a freeze-proof system. It uses a small pump with small energy use. The disadvantages? Lots of expensive parts, including a complex controller, and the need for periodic inspection and maintenance. However, in any application with a limited supply of water, the daily dumping of water from the collectors onto the ground will be an issue.
The re-circulation system has the advantage of using a standard hot water heater to double as the storage tank. And it's freeze-proof if the system is small. It has the disadvantage of wasting a lot of energy. If it's really cold, the backup heating system, say an electric element, has to heat water that is simply being radiated away from the collector at a significant rate.
The active closed-loop system (Fig. 9) is freeze-proof and contains quality components. One disadvantage is that it is complex, meaning it has pumps, valves, and various controls. The tank with heat exchanger is expensive but adds a lot of useful, well-insulated thermal mass to the system. If utility-powered, the pump won't work during a blackout.
Mh: There's merit to the idea that if the system depends on electricity, the electricity should be generated from the sun, too. If there's sun for the collectors, there's sunlight to make electricity to power the pump and move the heat.

In all of these systems, if the collectors overheat, a T&P relief valve will provide protection. There's a down side with the T&P valve blowing. First, it gives away a lot of hot water since the valve won't close until both the temperature and pressure fall. And, second, dumping the heat transfer medium can be expensive—if it's a glycol/water mixture.
I want to thank you, Rob, for turning me onto the fact that a P-type (pressure-only) relief valve is manufactured. I want to use one of these in my next installation. I suspect it will keep the system from dumping all the hot water since it should close as quickly as the pressure is relieved. The pipes in the collector can take heat, but have a tougher time surviving pressure.
Rob: I guess my critique of the advantages and disadvantages of these systems reveals my bias. Generally, I have found with solar hot water, the simpler the better. The simple systems seem to last longer, as a rule.

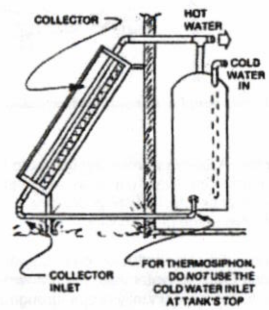


Fig. 12: Avoid the standard cold water inlet for thermosiphon flow.

Mh: Bias? I appreciate your review and advice. I've learned a lot. Will you describe how you size a system to the application and match components with each other?

Rob: Almost every hot water system has a backup. I design for 70% solar usage. A four-person family is a good standard. Two 4x8-foot collectors will supply the hot water needs of four people. The tank should be sized to the array. In my climate, I've found that 1.8 gallons of fluid per square foot of collector is a good ratio. So, two collectors of 32 square feet each will require a storage tank of 115-gallon capacity. For radiant floors, I've found that the collector area should be about 10% of the floor area. The same two 4x8-foot collectors, then, will handle about 650 square feet of radiant floor.

Mh: What's the average cost of water heating with electricity, propane, and natural gas for a 4-person family?

Rob: Yes. Using electricity at 12¢ per kWh, the cost of water heating is about $46

from the collector are high at night, so there is definitely a time of optimal use of the hot water produced, usually afternoons and evenings. The collector/tank combination is heavy, too. Filled, it may reach 650 pounds and tax an unreinforced roof.

The newer ProgressiveTube™ collectors of this type (Fig. 5) are simple and use 4-inch copper tubes and fins with special "selective" surfaces. They extract more of the sun's energy than blackened surfaces and resist re-radiation of this energy at night. I recommend ProgressiveTube™ systems for my climate zone.
The thermosiphon system has the advantages of simplicity and good efficiency. It doesn't require electricity and is therefore unaffected by a utility blackout. One disadvantage of thermosiphon flow is that the plumbing must follow strict guidelines—bigger tubing, gentle turns, no low spots, and no restrictive valves—to ensure a smooth, unrestricted flow. An air pocket at a high spot or a large bubble somewhere in the system will stop thermosiphon flow.
Mh: I'd like to add to your comments on thermosiphon. I've found this to be a neat, natural way to move heat from a collector to storage or use. Water pumping in rural locations can eat a big portion of anybody's energy pie. Any process that will pump water and the heat it contains through a pipe without external power is a blessing. But—thermosiphon will not tolerate poor planning or a sloppy installation. It wants free, unrestricted motion. Even the check valve must be a gravity-type rather than a pressure-type to avoid becoming restrictive.

Tests have shown that thermosiphon doesn't start until the collector reaches a critical temperature (Fig.10). Flow commences rapidly, slowing to a more constant rate. A bubble big enough to block a tube will stop flow immediately. The collectors can get hot enough to blow a T&P valve and still no flow. It's exciting to see water and steam shooting up into the air but, alas, not very productive. Steeply-pitched pipes will ensure a good flow.
I know that in-line, centrifugal-type pumps are used in radiant floor systems to periodically purge the thermosiphon loops of air bubbles. Theoretically, thermosiphon can push water through the pump when it's off. The pump has another use. It enables the owner to pump more heat into the floor from storage at night.
I added a small purge-pump to one thermosiphon system in the 1970s. I wanted to use primarily thermosiphon but the system included existing plumbing—naturally inaccessible—and the thermosiphon flow kept getting blocked with bubbles. I added a small 12-volt pump in parallel with the check valve (Fig. 11) to occasionally purge the system with a faster flow rate. I used a positive-displacement type to avoid any flow of fluid through the pump when it was off.
Rob: I'll go on. The three-season system has the advantages of using the existing water heater as a backup, being inexpensive, and requiring only a small pump. The disadvantages are that it is susceptible to freezing and depends on the owner being there to drain it when the weather is cold. There is an overall limit to the size of this system when it's plumbed to a water heater of a specific capacity.

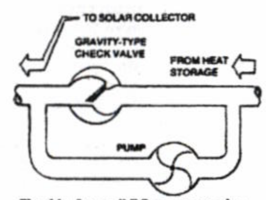


Fig. 11: A small DC pump can be used to purge the systems's lines of air bubbles

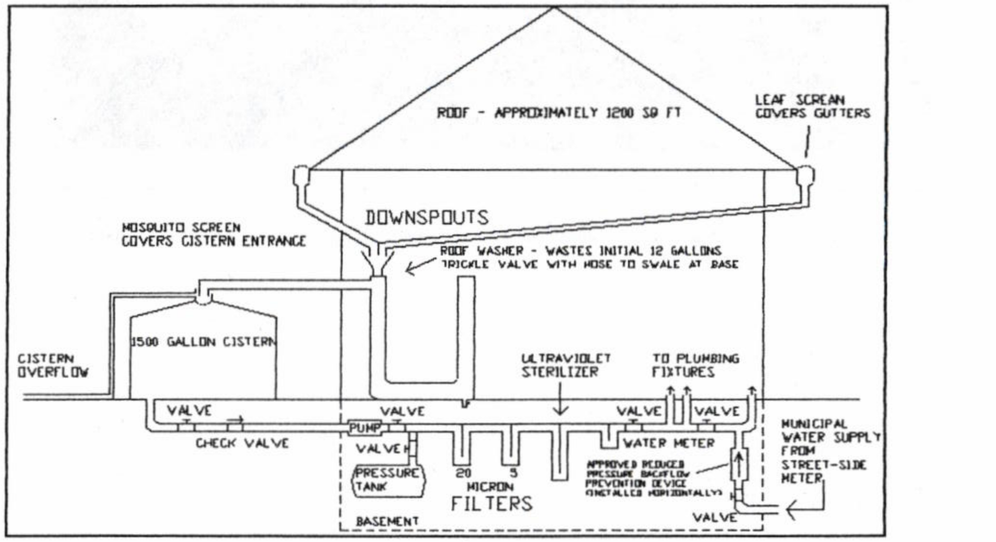
The drain-back system (Fig. 1) is relatively simple, versatile, and freeze-proof. The tank used in this type of system is long-lasting and there is little maintenance required. During a blackout (or other loss of electricity to the system), the panels are empty and will not overheat. It's even possible to set up the system so that thermosiphon will get the heat to your water heater. The disadvantages are most evident in off-grid systems, where the energy used in pumping is relatively high. This is because the pump must be sized to fill the collectors daily rather than just circulate water through them. As well, the tank must be located below the panels so that the water

use larger diameters. Portland's chief residential plumbing inspector commented that our use of ABS didn't conform to code as plastic may eventually decay in sunlight. Therefore, you should use copper, iron, or other sunlight-resistant materials to be completely correct.

Rainbarrels. A rainwater harvesting system can be as simple as a barrel connected to a downspout. Check the Rainbarrel Tutorial for tips on how to put together a system for as little as $15-20. One of our neighbors has connected his rainbarrel to his basement washing machine and gets virtually all his laundry water from this super-soft source for a miniscule investment.

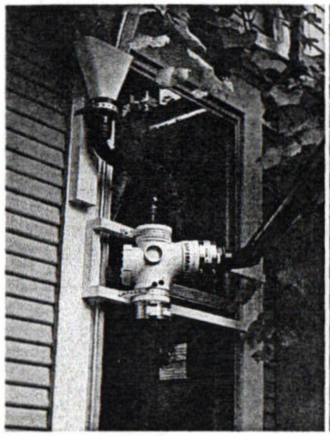
One notable advantage of rainwater is its softness. Rainfall in the Portland area contains about 5 mg/liter of dissolved minerals. Compare this with some hard groundwater which exceeds 500 mg/liter. Portland city water, which has an exceptionally pure source, is rated at 18 mg/liter.

According to two officials in Alaska and Hawaii with whom I have communicated, there is a long established tradition of rainwater collection in some parts of their states. According to Sourcebook Harvested Rainwater, in some areas of the Caribbean, new houses are required to have rainwater capture systems. Hawaii apparently is currently developing (or has already developed) guidelines. In Oregon, there is no regulation of water quality for individual residences – this is left up to the homeowner. The only regulations I have come across relating to rainwater harvesting are from Ohio, whose Department of Health Administrative Code regulates private water systems. Note, in particular, Rules 3701-28-09 Continuous disinfection and 3701-28-13 Construction and surface design of cisterns, hauled water storage tanks, and roof washers.



Two other great resources for rainwater harvesting information are Warwick (Coventry, United Kingdom) University's Development Technology Unit Roofwater Harvesting Programme and the *roofwater harvesting listserve archives*.

Update Summer 2002 – A different style of roof washer. This summer we installed a commercially available roof washer that uses a programmable valve to divert a rain's first flow away from the cistern. A purported advantage is the absence of standing water that can stagnate and potentially contaminate the cistern water. (This could happen, for example, if the trickle valve on the conventional device were to clog or it were left closed.) Below are two photos of the system with this new device. The first photo shows the roof washer mounted on a window frame near the cistern. Rainwater, which enters from the two downspouts above, can be observed from inside the dwelling. The first flush is diverted downwards into a holding barrel. An overflow hose from the top of the cistern also empties into this barrel. Post-flush water enters the cistern via the roof washer's side port through a screened cistern entry hole. The barrel overflow is directed to a swale in the middle of our back yard.



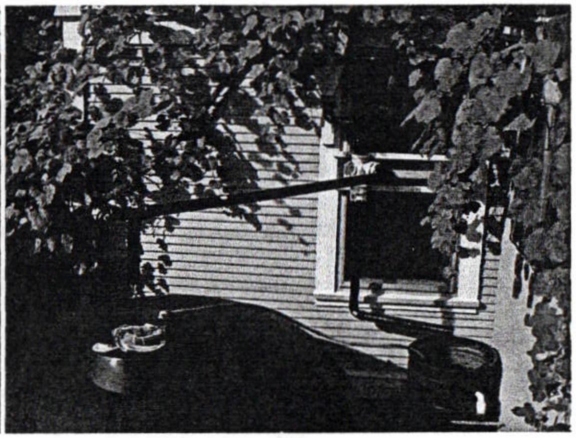


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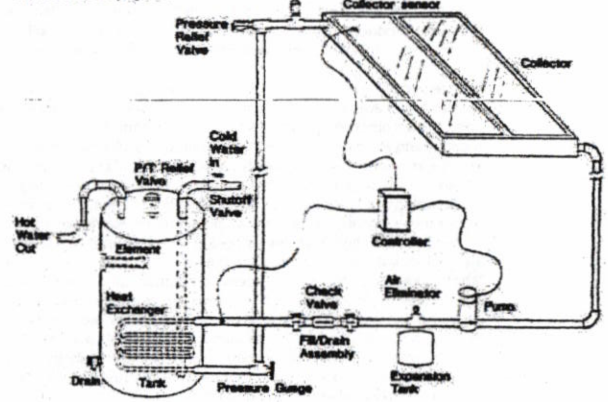
Fig 9: Components of an active closed-loop system



Incidentally, there are some types of systems that don't really fit into any of these seven categories.
The popular Copper-Cricket™ is one example. This system used a 20% methanol mixture under a vacuum to actually "pump" heated fluid down to a storage tank without a pump. It operates on the same principle demonstrated in a coffee percolator to transfer heat. Another is the Sun™-family of solar thermal collectors. These use columns of evacuated tubes to collect and transfer heat.
There's more basic stuff, too. Some folks just spiral plastic pipe on the ground to pre-heat the water that goes into their standard water heater. It works but if a sudden freeze doesn't ruin it, long term exposure of the plastic pipe to sunlight will.
Mh: The softer, more flexible black plastic tubing you're referring to is identified as PE, or polyethylene tubing. Ultraviolet radiation from the sun breaks down any kind of plastic, disintegrating the bonds of the polymers and turning the plastic brittle. The black tubing sold in rolls is neither designed to work in direct sunlight nor withstand elevated temperatures. Hot water, particularly with soft water, will leach stabilizers and joint cement from the tubing, too. This is great for showers but you don't want to drink this water or cook with it.

Rob: If there's one thing I've observed, it's that most folks who build their own system try to re-invent the wheel, and their designs sometimes reflect a lack of understanding of the basic principles. With good plans, most people could build a good system. Still, many folks don't want to do it themselves.

Mh: I prefer doing my own system yet I have to admit that I have often overrated my ability to be there when the system really needed me. Rob, will you go back through the list of systems and give us your thoughts on the advantages and disadvantages of each type?

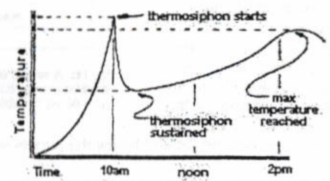


Fig. 10: The temperature needed to start thermosiphon flow is greater than the one that will sustain it.

Rob: The integral collector/storage system has the advantages of low cost, simplicity, and the lack of pumps or controls. Even homebuilt versions are long-lasting. The tank has enough thermal mass to avoid freezing except in hard-freeze areas. The disadvantages? This design is relatively inefficient and the water often doesn't reach a very high temperature because the glass-to-mass ratio is small in a